



nEXO R&D

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Feb. 5, 2015

Workshop on the Intermediate Neutrino Program
Brookhaven National Lab, Upton, NY

Xenon is an Excellent Candidate for Large Double Beta Decay Search

Xenon isotopic enrichment is easier. Xe is already a gas & Xe^{136} is the heaviest isotope.

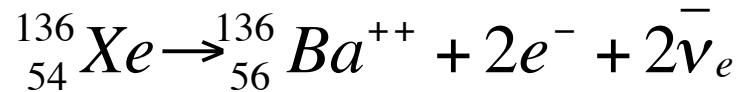
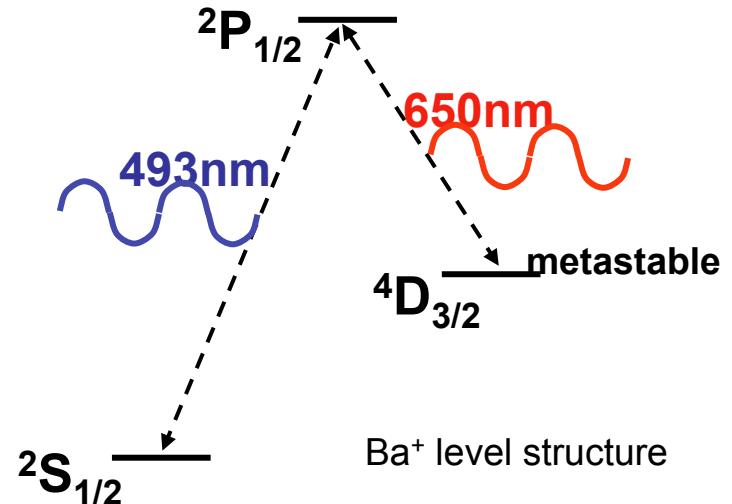
Xenon is “reusable”. Can be repurified & recycled into new detector (no crystal growth).

Monolithic detector. LXe is self shielding, surface contamination minimized.

Minimal cosmogenic activation. No long lived radioactive isotopes of Xe.

Good energy resolution in LXe. Scintillation light/ionization correlation.

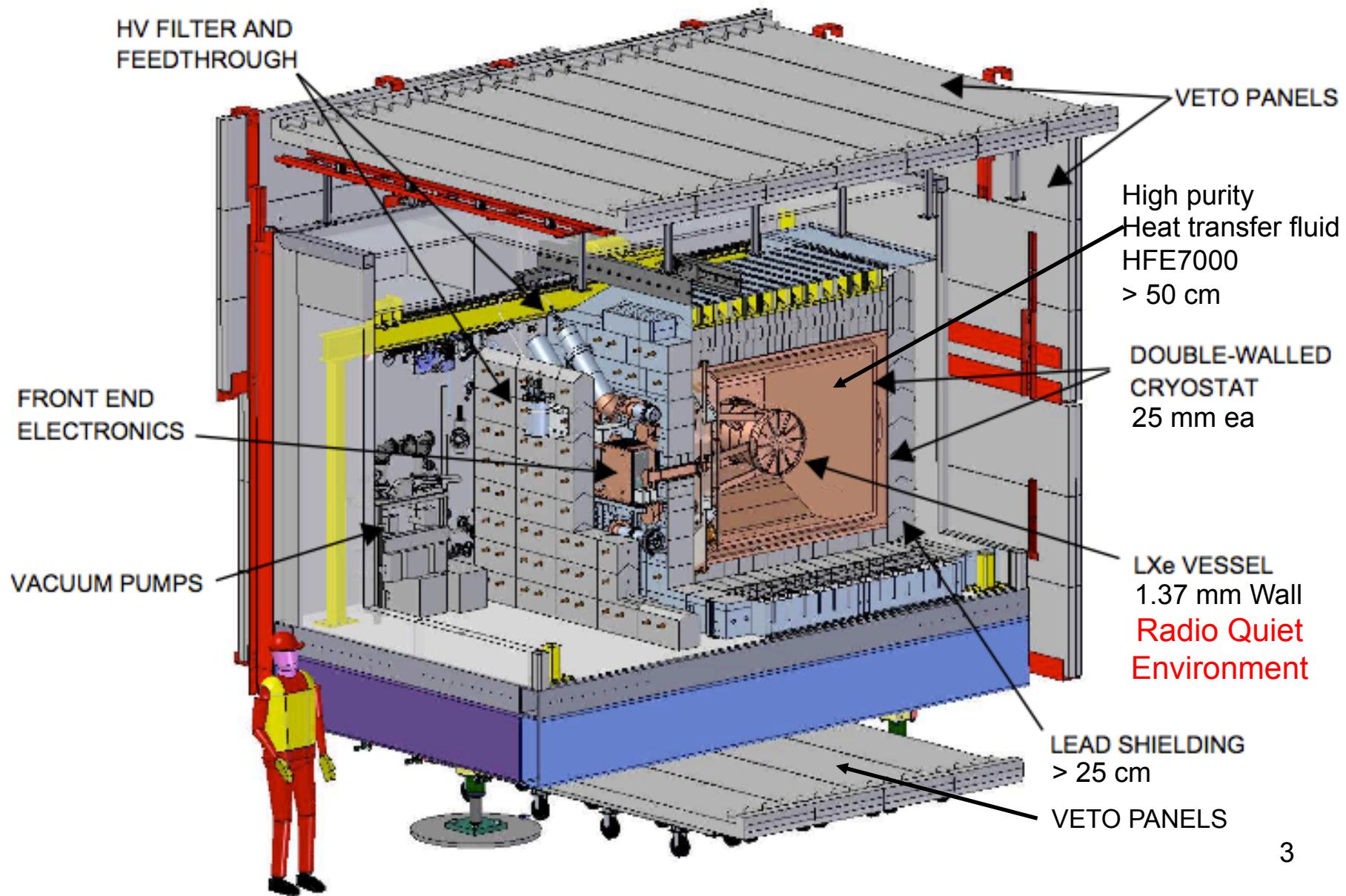
Good $\beta\beta$ and gamma discrimination. 3-D cluster reconstruction.



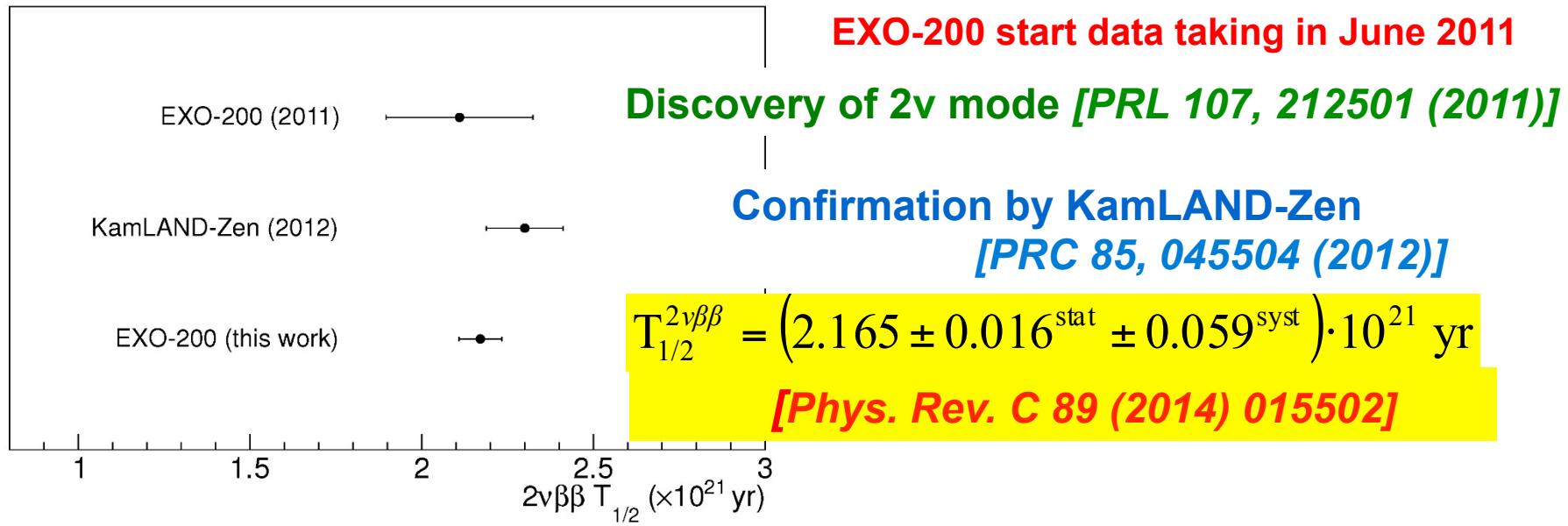
... admits a novel coincidence technique.
Background reduction by Ba daughter tagging.

M.K. Moe, Phys. Rev. C 44 (1991) R931

The EXO-200 Detector

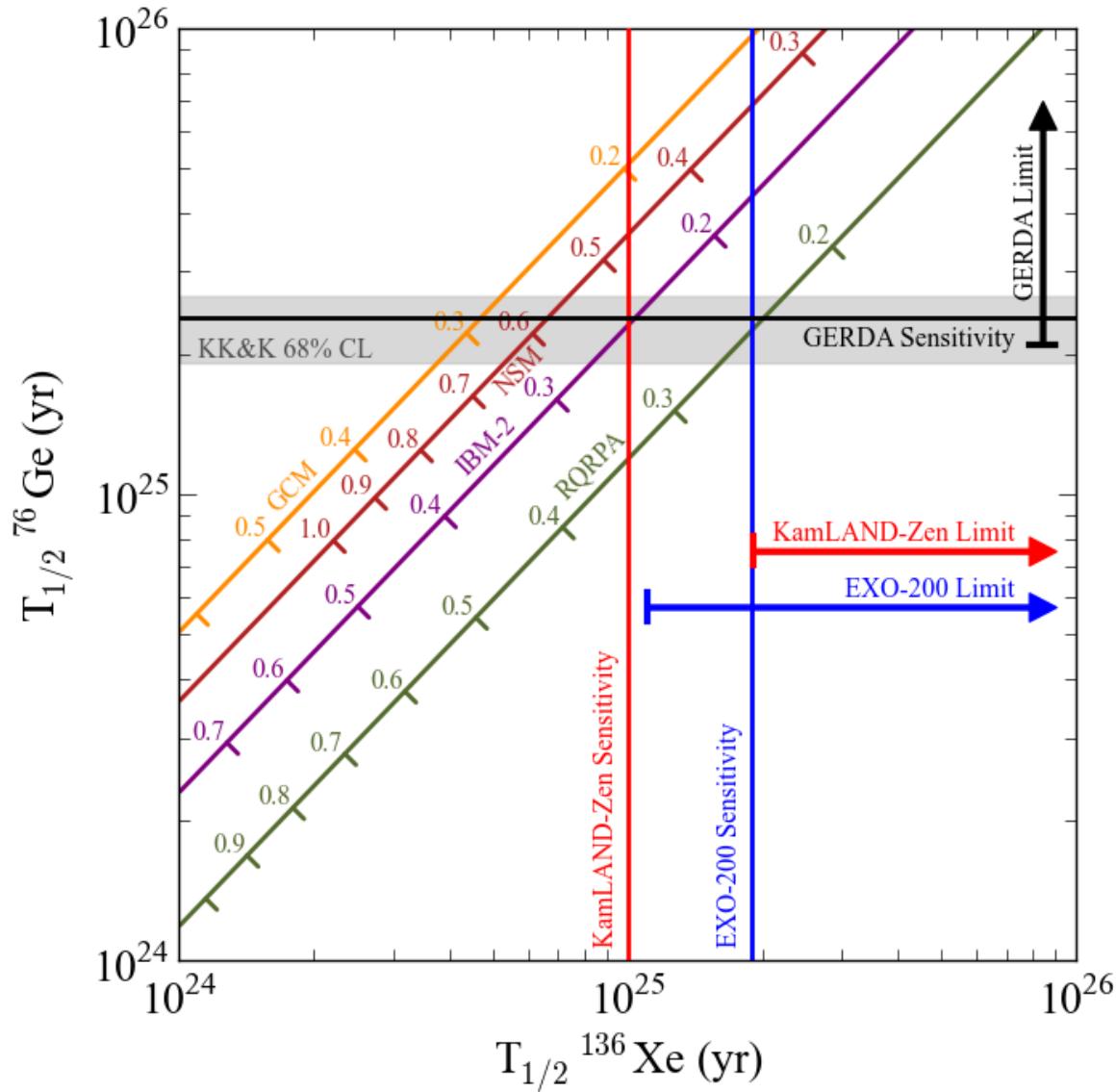


Precision ^{136}Xe $2\nu\beta\beta$ Measurement



Longest and most precisely measured $2\nu\beta\beta$ half-life

Comparison of $0\nu\beta\beta$ Measurements



$T_{1/2} {}^{0\nu\beta\beta} > 1.1 \cdot 10^{25} \text{ yr}$ (90%CL)

$\langle m_\nu \rangle < 190 - 450 \text{ meV}$

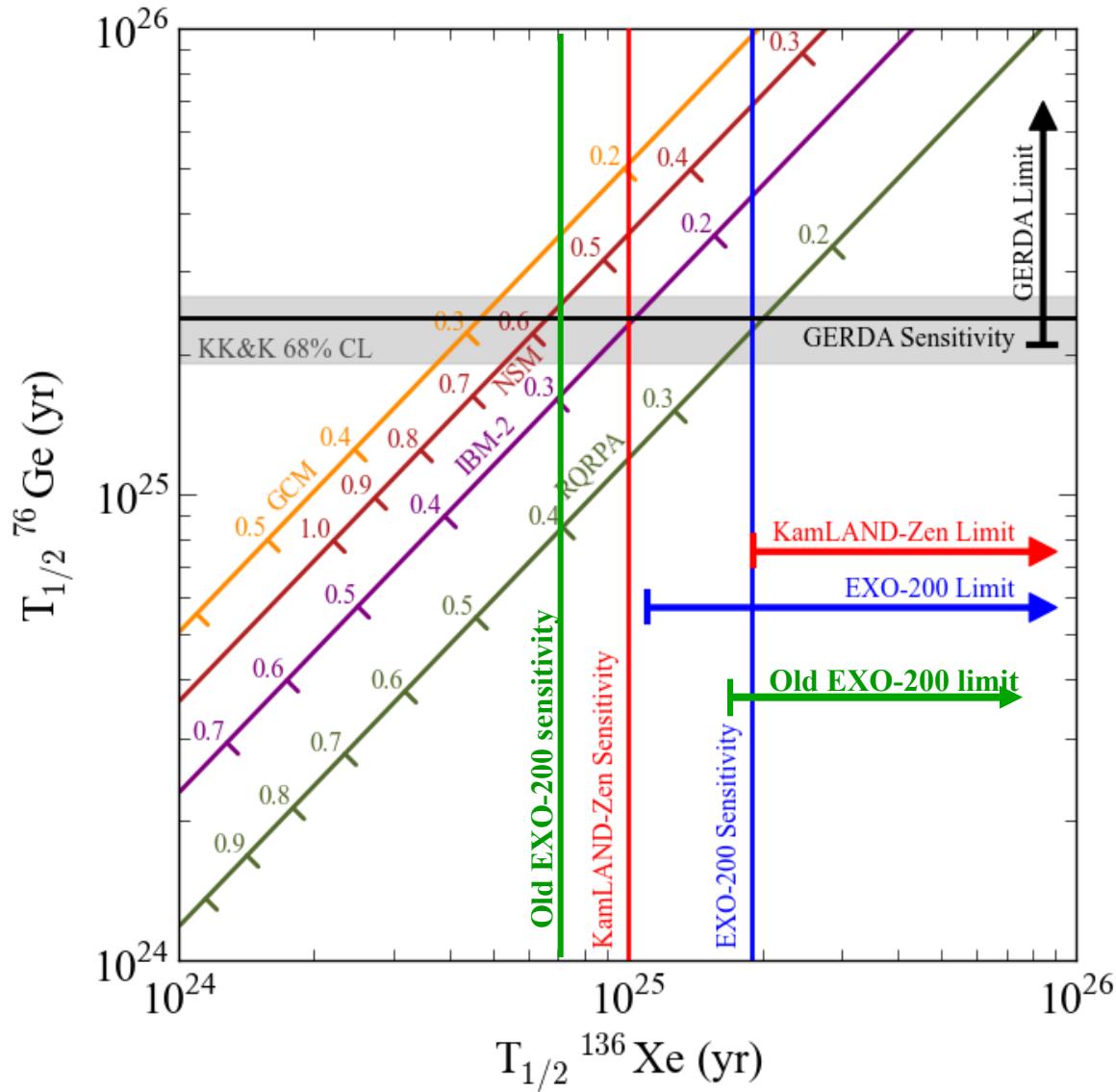
Average $T_{1/2} {}^{0\nu\beta\beta}$ sensitivity:
 $1.9 \cdot 10^{25} \text{ yr}$

J.B.Albert et al. (EXO-200)
Nature 510, 229-234 (2014)

A. Gando et al. (KamLAND-ZEN)
PRL 110 (2013) 062502

M. Agostini et al. (GERDA)
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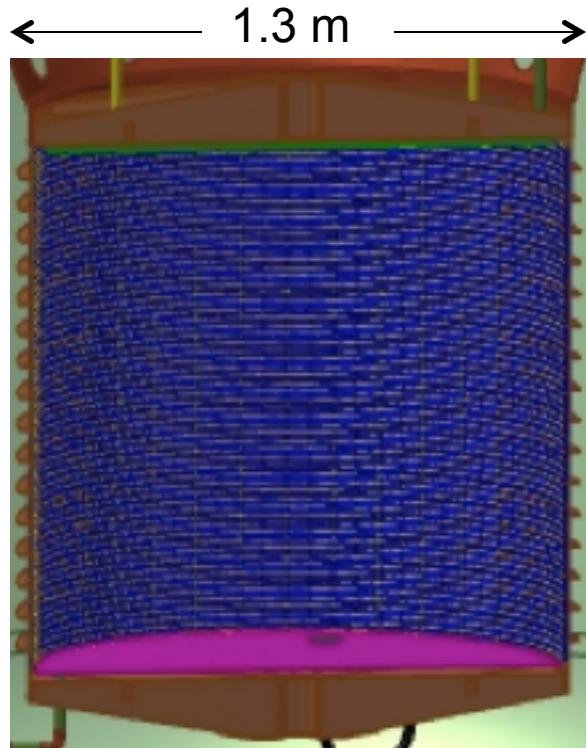
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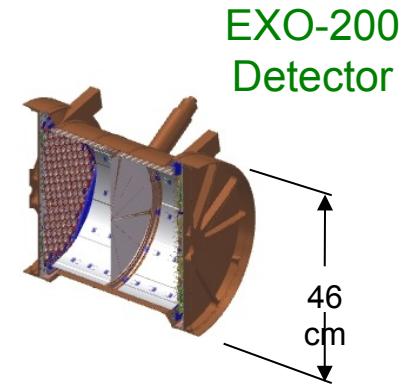
M. Auger et al. (EXO-200)
PRL 109 (2012) 032505

From EXO-200 to nEXO Detector

- EXO-200 have achieved design energy resolution, background goal and SS/MS rejection capability.
- nEXO is a 5 tonne LXe TPC with better detector performance, *initially* without Ba-tagging.
- 4.7 tonnes of active ^{enr}Xe (80% or higher), $< 1.0\% (\sigma)$ energy resolution.
- Assuming observed EXO-200 backgrounds. $\beta\beta$ scales like the volume, most backgrounds scale like the surface area.

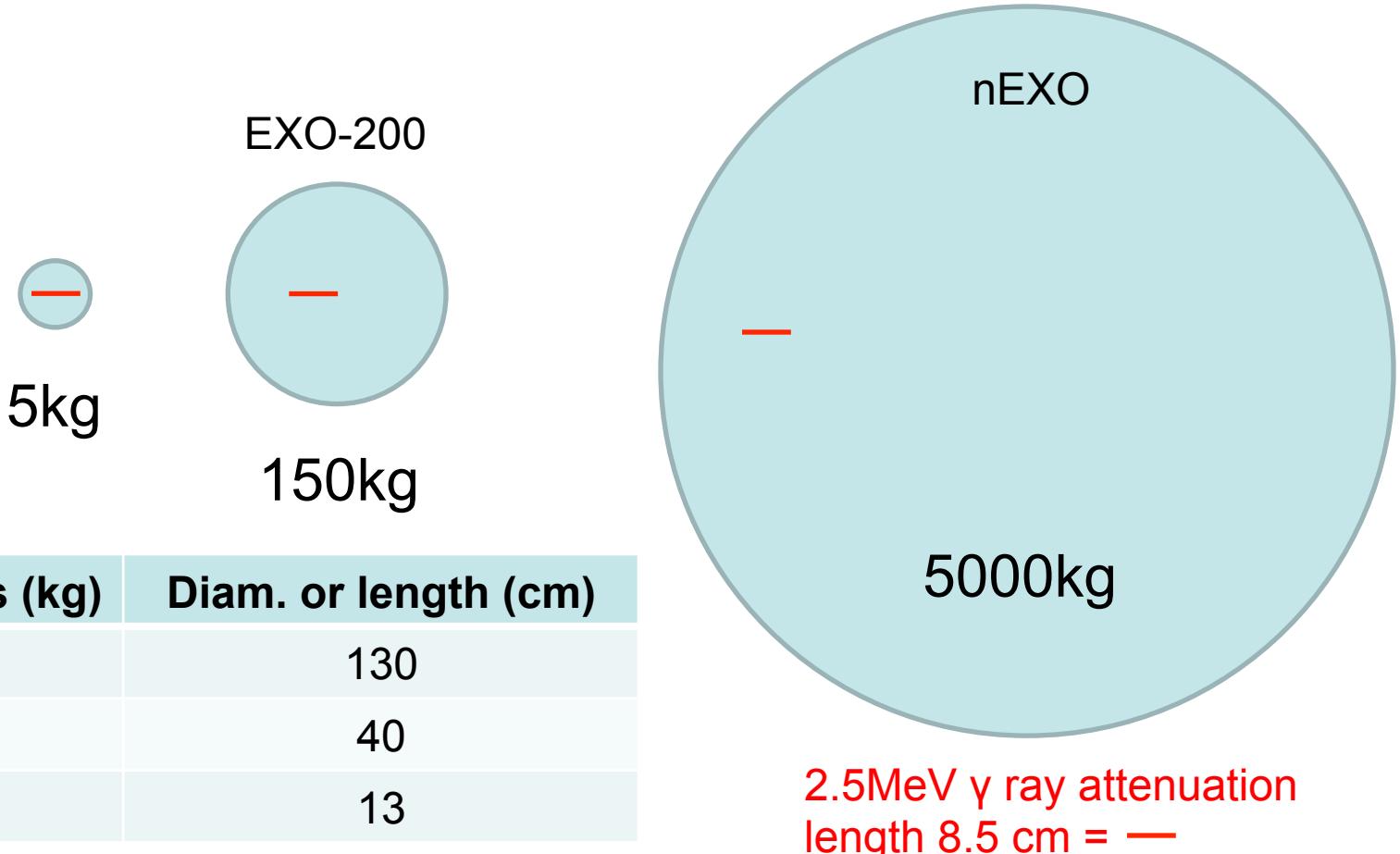


nEXO
Detector



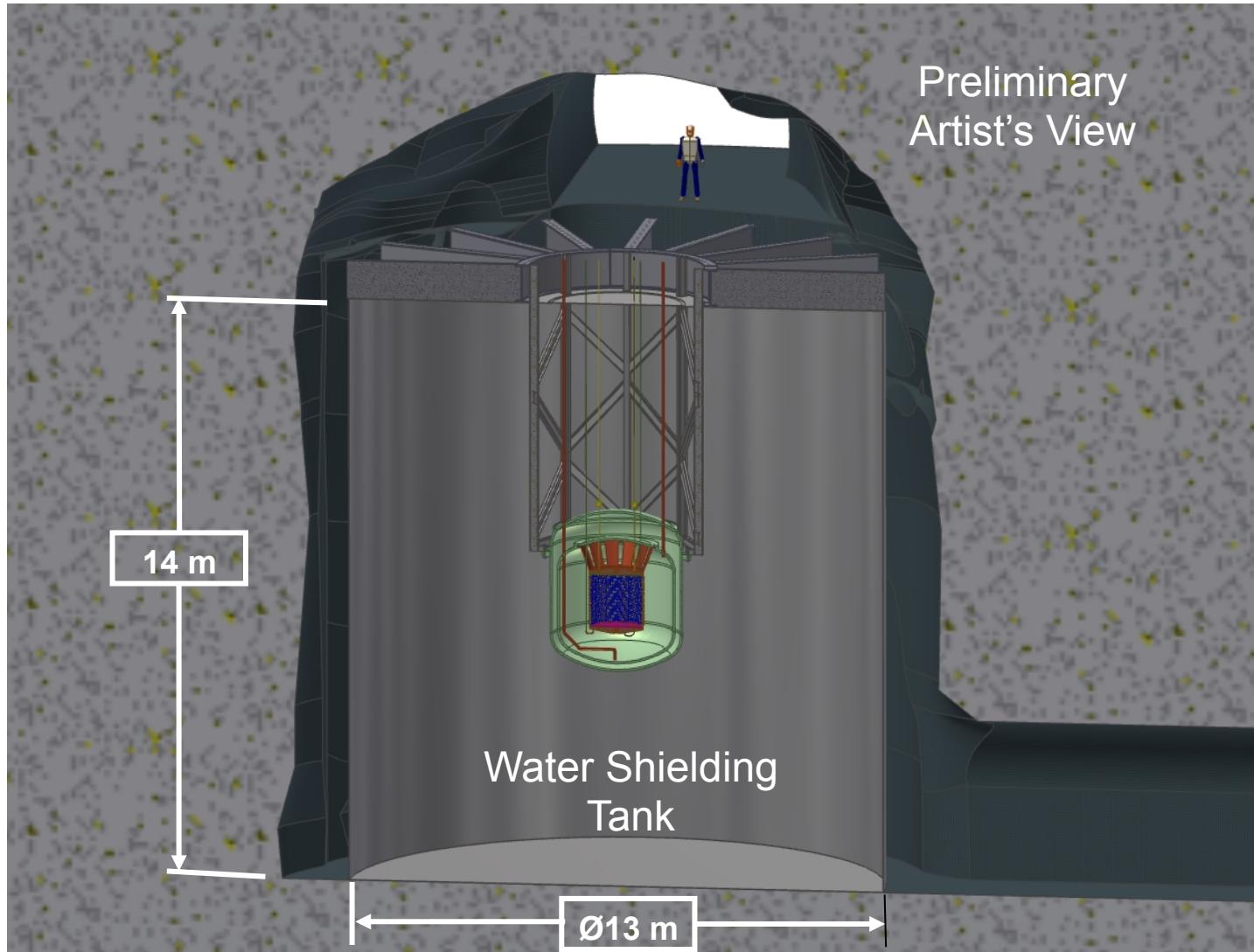
EXO-200
Detector

nEXO: a Monolithic Detector



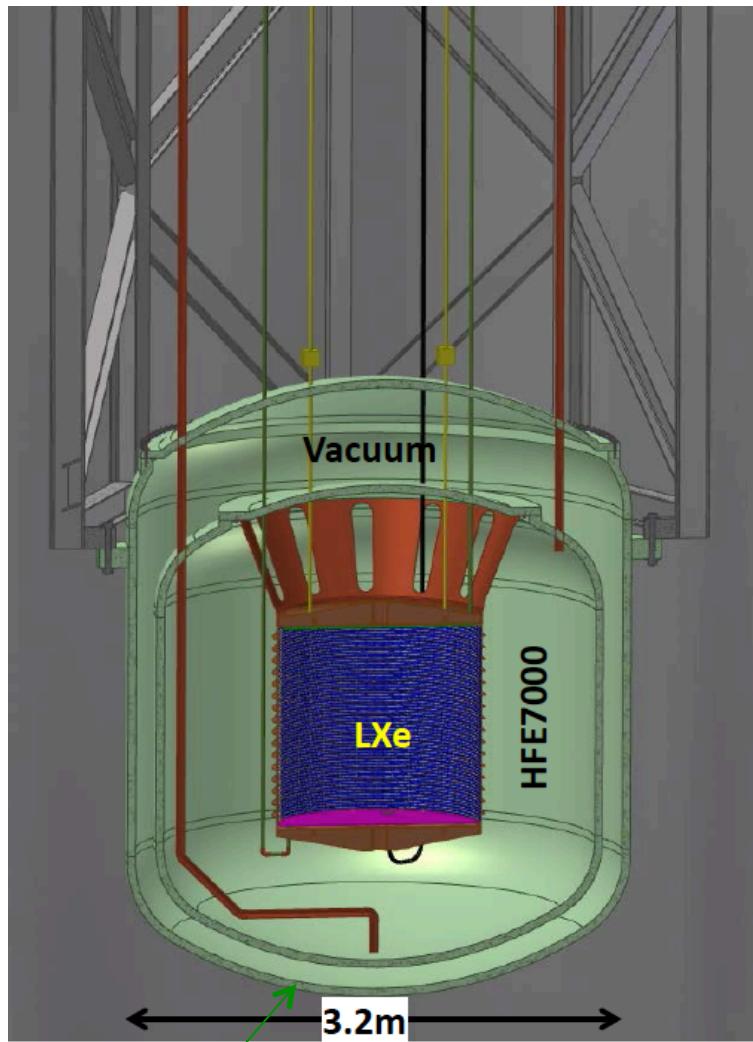
**Monolithic detector is essential: Self-Shielding,
containment of Compton scattering, inner fiducial
volume extremely clean**

nEXO in the SNOlab Cryopit



6,000 m.w.e. depth sufficient to shield cosmogenic background.

Low background cryostat

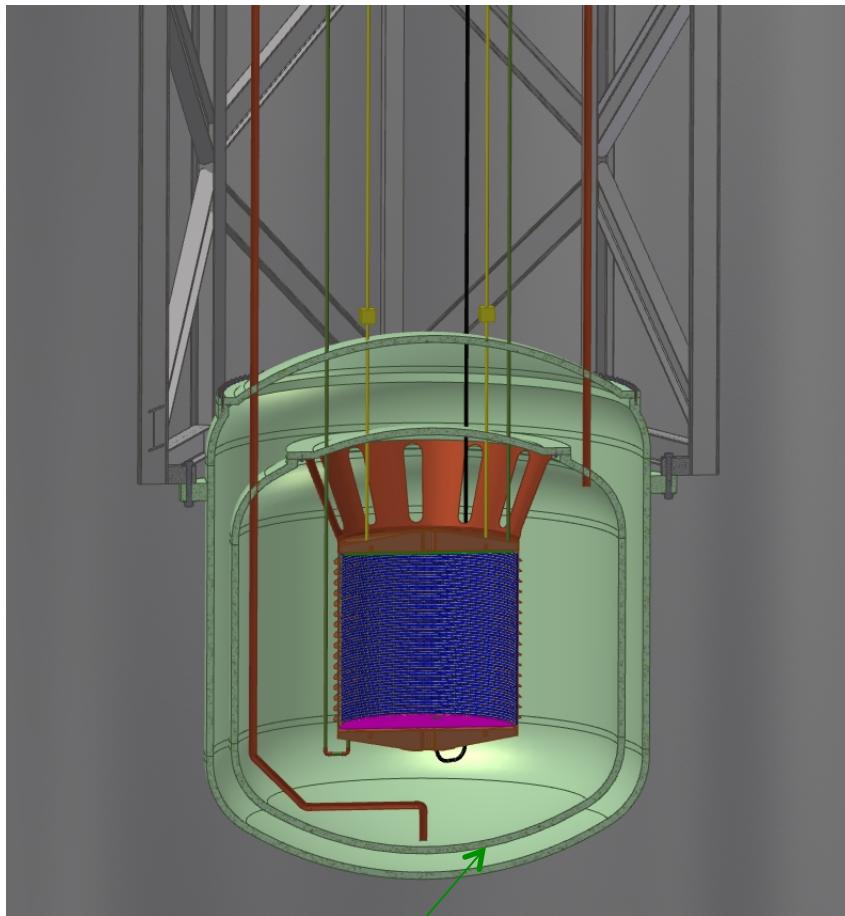


- Determine the feasibility of a composite cryostat.
- Ease of construction underground.
- Can have lower background.

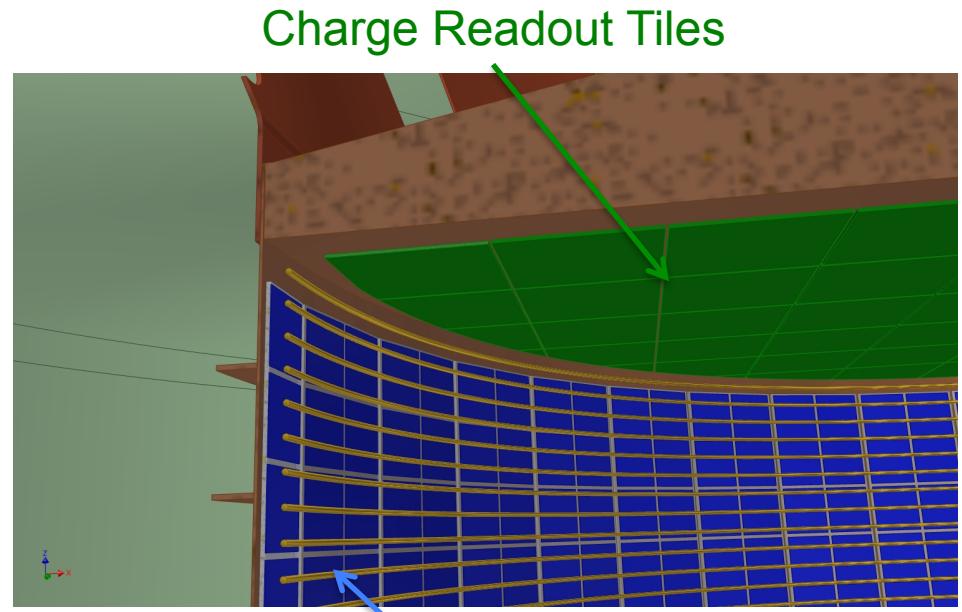
R&D activities:

- Develop low temperature feedthrough.
- Measure radio-purity of carbon composites.
- Simulate background impact.

nEXO TPC Conceptual Design (artist's view)



Carbon Fiber Cryostat



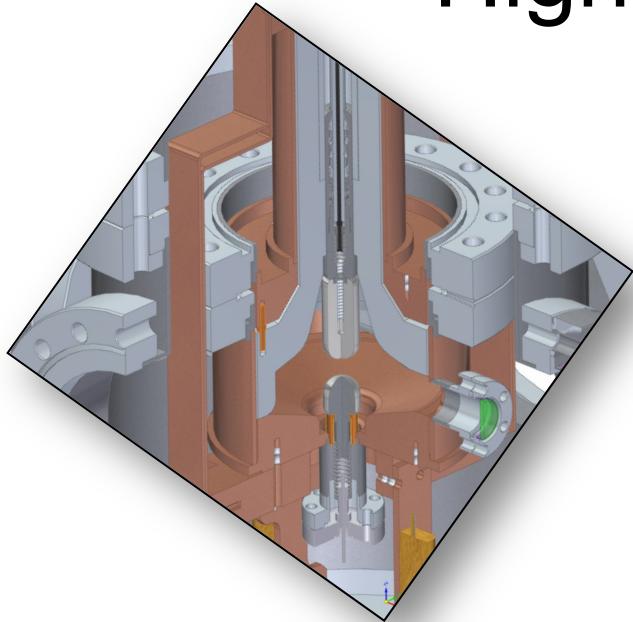
Charge Readout Tiles

Silicon Photomultipliers (SiPMs)

Baseline concept: (Improved TPC design).

- Single drift volume
- Charge collection on the anode plane
- Light collection on the barrel behind field shaping rings

High-Voltage Tests

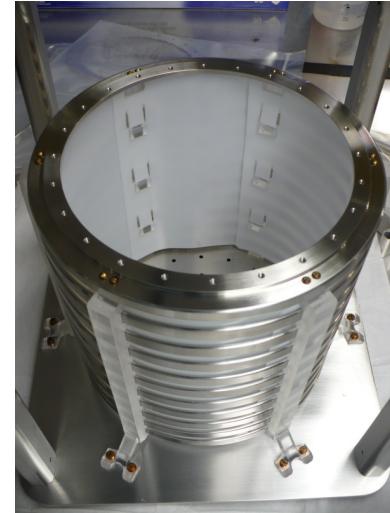


Phase I : Test fundamental LXe HV issues, small parts

Achieve required HV for nEXO.

R&D activities:

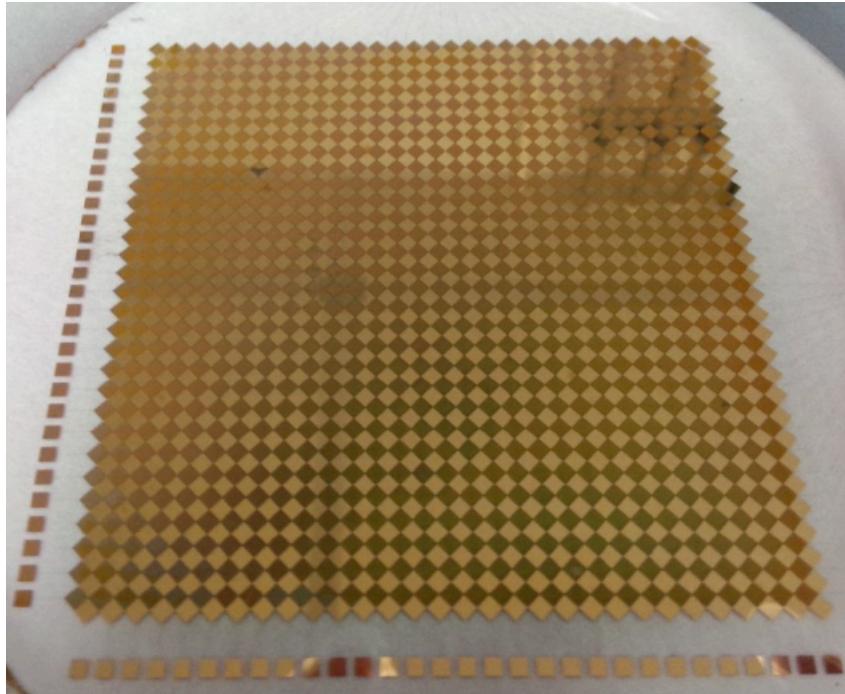
- Determine the fundamental HV issues in LXe small setups.
- Test full scale TPC parts under HV in LXe.



Phase II : Test EXO-200 parts, long-term effects

Phase III : Test full scale nEXO prototype designs

Charge Collection Tiles

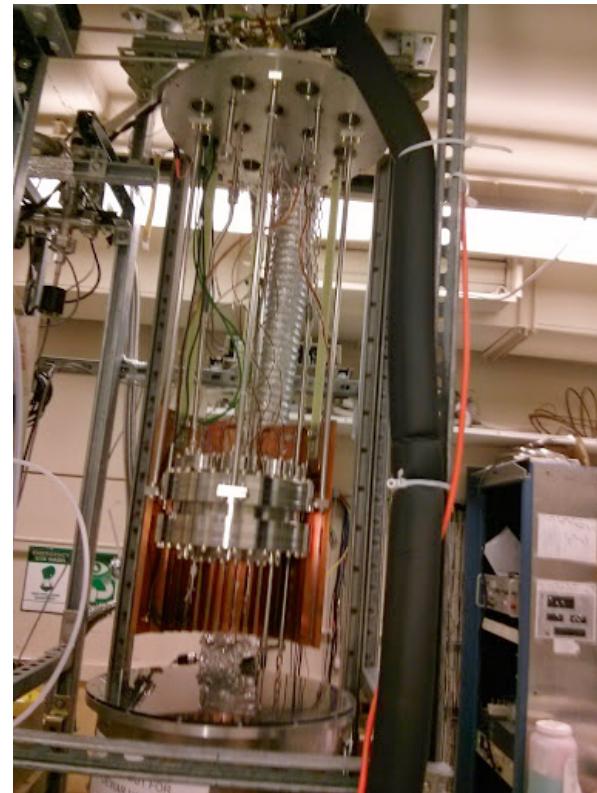


Prototype Charge Readout Quartz Tile

- **Improve $\beta\beta$ and gamma discrimination**
- **Lower background from readout structures**

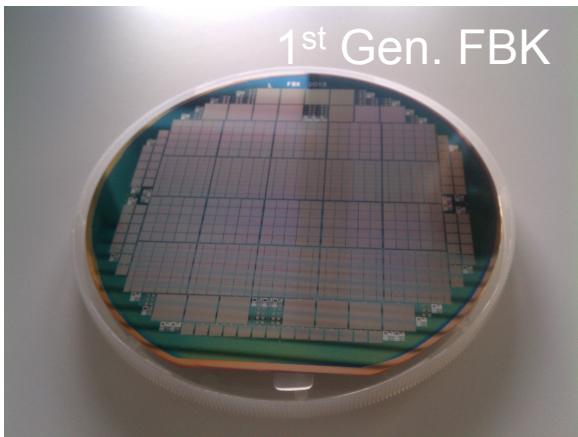
R&D activities:

- Develop charge readout structures on low background substrates.
- Simulate and measure charge collection in LXe and SS/MS discrimination.

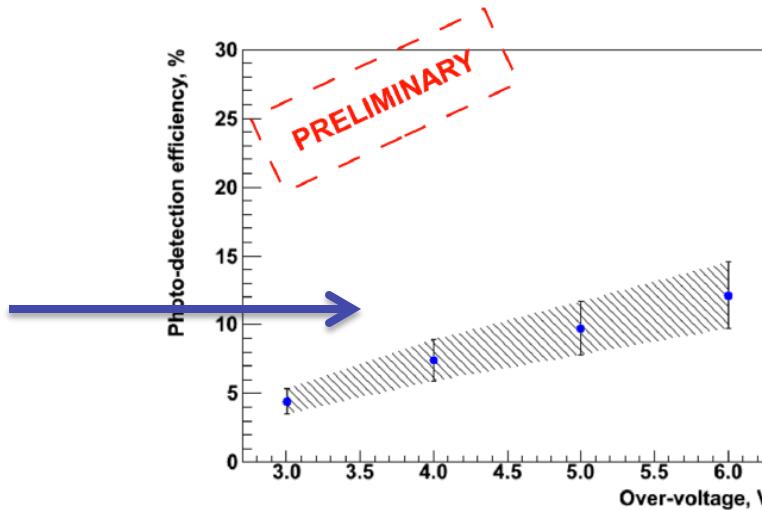


Charge Readout LXe test apparatus

UV Sensitive SiPM

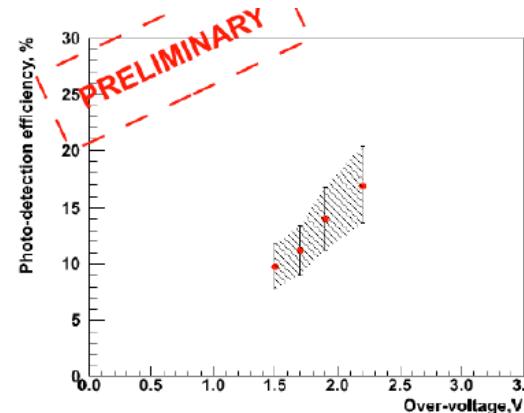


1st Gen. FBK



2nd Gen. FBK
has improved
performance.

Hamamatsu MEG device



Need low
background
packaging

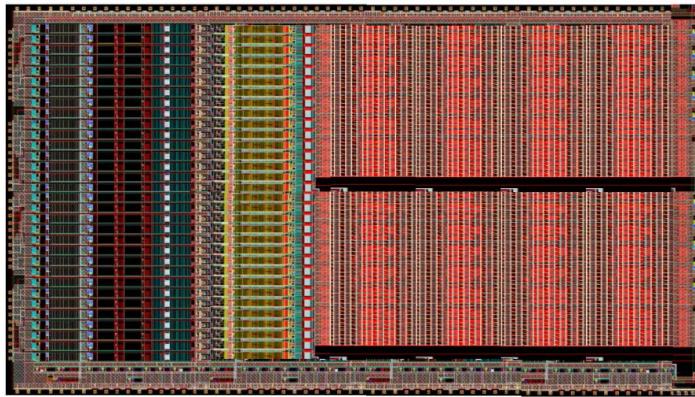
- **Higher light collection efficiency.**
- **Lower background photo-sensor.**

Photon Detection Efficiency Measurements

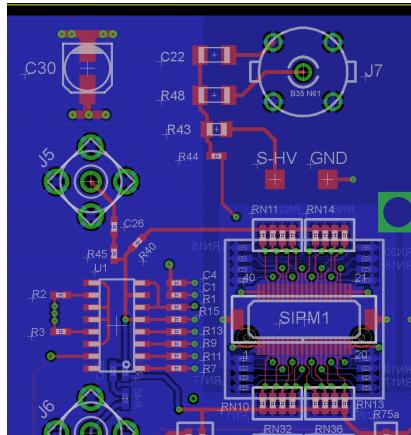
R&D activities:

- Develop SiPMs with > 15% photon detection efficiency for 180 nm light.
- Determine the intrinsic radio-purity of SiPM.

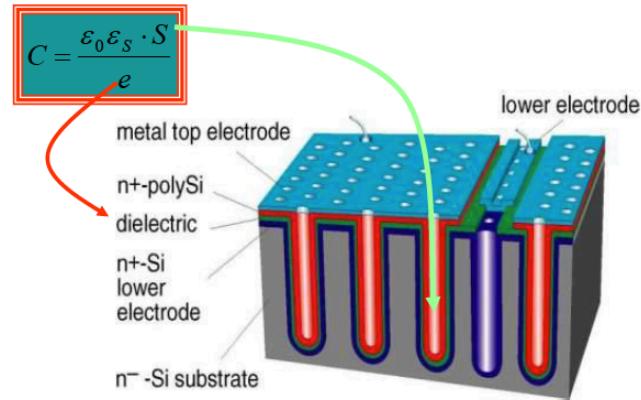
Cold Frond-End Readout



Concept of Cold Charge
readout ASIC



Prototype circuit for SiPM



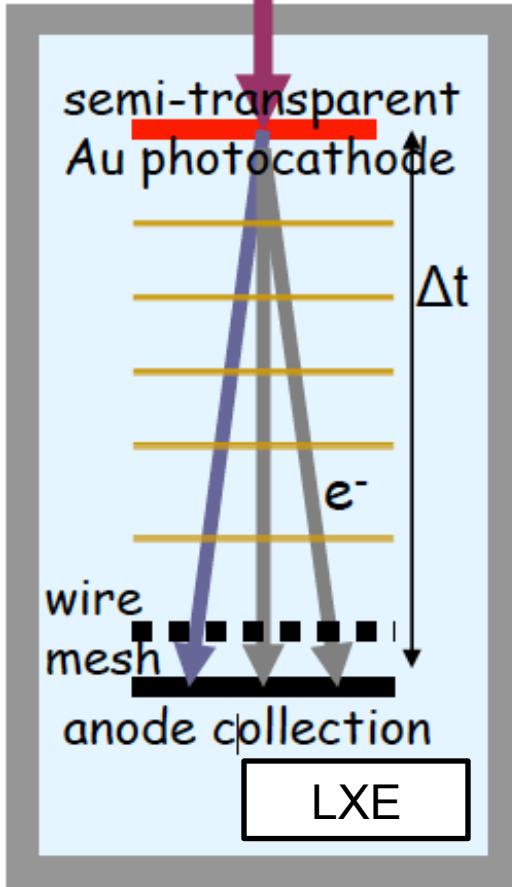
Si Capacitors Testing

- **Improve detector energy resolution.**
- **Signal multiplexing to reduce cables and feedthroughs.**

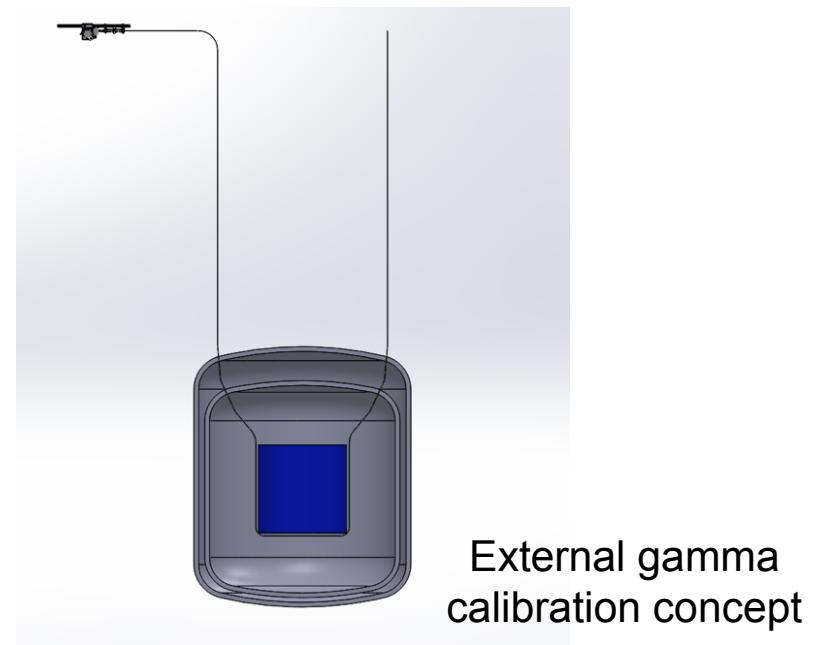
R&D activities:

- Develop low background, low noise in LXe front electronics for charge readout and SiPMs.
- Develop low background critical components (capacitor, cable, etc)

Detector Calibration



Photocathode in LXe Tests



**Develop calibration methods for nEXO:
purity, energy scale, etc.**

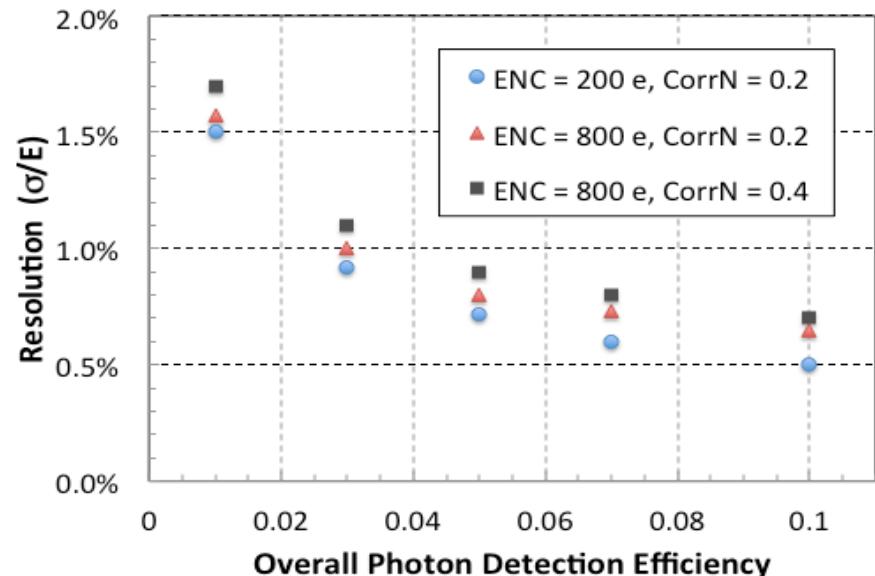
R&D activities:

- Photocathode in LXe or laser Xe ionization for purity measurements.
- Develop external and internal calibration sources

Radio-Assay and Detector Simulation



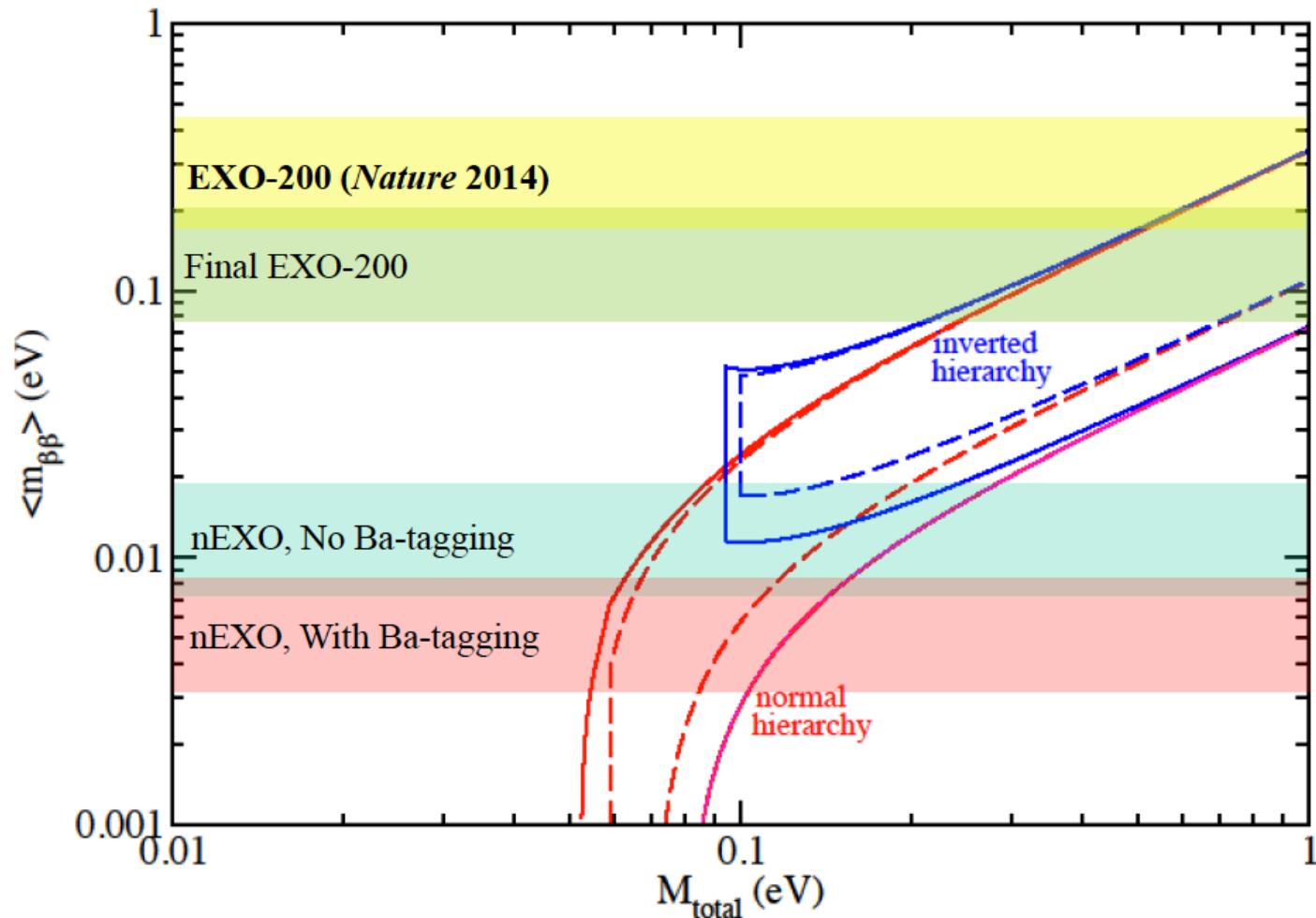
Ge Detector Lab at UA



Detector Energy Resolution Simulation

- Several existing and planned Ge counting, NAA, ICPMS, Rn counting facilities for nEXO material assay.
- Active efforts in background and detector performance simulation (energy resolution, SS/MS, etc.)

nEXO Sensitivity



With 5 year of data, nEXO (no Ba-tagging) can reach Majorana neutrino mass sensitivity of 7-18 meV.

Conclusion

- EXO-200 successfully demonstrated the LXe TPC technology as one of the leading candidates for tonne scale $0\nu\beta\beta$ decay experiments.
- nEXO has an active R&D program within US and with international collaborators to enhance the detector performance and reduce detector background, hence extend its physics reach.
- Many R&D efforts (HV, photo-sensor, cold electronics...) can benefit other large scale noble liquid detectors, and create synergy among different types of experiments: $0\nu\beta\beta$, dark matter, SB/LB neutrino oscillation, etc.

The nEXO Collaboration



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